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AN EVALUATION OF THREE SEASONS OF ANTI-LIGHTNING OPERATIONS IN CALIFORNIA

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Any wildfire is hazardous. Lightning-caused wildfires are especially so when many are started in rough country. In an attempt to reduce this hazard, the California Division of Forestry (C.D.F.) has been actively engaged in cloud seeding to suppress lightning fires in northern California for some time. A Division publication, "Modification of Orographic Thunderstorms for Lightning Control, 1956 Progress Report," describes these anti-lightning activities from 1951 through 1956.

In mid-1957, about halfway through the summer's operation, the California Division of Forestry contracted with the Forest Service through its experiment station at Berkeley to provide technical advice and evaluation, for that year, and, through later contract renewals, for 1958 and 1959 as well.

This report summarizes the main points of the evaluation of the 1957, 1958, and 1959 operations. These are taken directly from the final report to the California Division of Forestry. The basic data and details of study methods are given in that report (loan copy available from Division of Forest Fire Research, Pacific Southwest Forest and Range Experiment Station, Berkeley 1, California).

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Angencies Involved

The California Division of Forestry initiated, supported, and conducted the seeding program. Much of the field work was done by personnel of the Lassen-Modoc Ranger Unit, headquartered at Susanville, California.

Each summer in 1957, 1958, and 1959, the Division of Forestry distributed 50 silver iodide particle generators to State and Federal ranger headquarters, suppression crew stations, lookouts, guard stations, and other locations in northeastern California (C.D.F. District II), where lightning-caused fires are most numerous. 1/

Ground-based generators were distributed over about 6,000 square miles around Lassen Peak in 1957, 3,000 square miles in southern Lassen and eastern Plumas counties in 1958, and 600 square miles around Eagle Lake (Lassen County) in 1959. A "Project Skyfire"-type generator was used in 1957 and 1958; a pressurized-type generator was used in 1959. In 1957 the C.D.F. also conducted aerial seeding over northwestern California.

Active cooperators were:

1. Region 5, U. S. Forest Service, especially personnel of the Lassen, Plumas, and Modoc National Forests.

2. California Department of Water Resources.

3. U. S. Weather Bureau, especially fire weather forecaster in Redding and Reno.

4. Westwood Fire Department in Westwood, California.

5. Pacific Southwest Forest and Range Experiment Station.

Methods

In 1957, neither the seeding from the ground nor the seeding with aircraft was randomized or otherwise statistically "designed." In 1958 and 1959, on advice of the Experiment Station, the C.D.F. conducted randomized, "designed" operations. In all three years the main evaluation problem was to estimate the effect of seeding on the incidence of lightning fires (this amounts to estimating what would have happened without seeding) and to calculate the probability of the effects arising by chance alone.

1/ Court, Arnold. Lightning fire incidence in northeastern California. U. S. Forest Serv. Pacific Southwest Forest and Range Expt. Sta. Tech. Paper 47, 21 pp., illus. 1960.

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For this purpose, multiple regression equations were used, with appropriate assumptions about the error term. To avoid biased regressions the evaulator needs a "design"--a detailed plan for measurement, randomized treatment, and analysis, formulated in advance and adhered to in operation. Randomization is most important. Besides lessening bias, it provides a basis for computing exact probabilities and a justification for computationally simpler approximations to these exact probabilities.

The regression analysis for the 1957 ground operations was based on annual counts of lightning fires--altogether 28 yearly totals, from 1930 through 1957. Study areas included the Lassen and Plumas National Forests, within the seeded area, and the Tahoe, Eldorado, and Stanislaus National Forests, where no seeding was done. An attempt to evaluate the 1957 aerial seeding operations in northwestern California ran into difficulties because no good control (unseeded) areas were available for comparison.

The regression analyses for 1958 and 1959 were based on daily counts of lightning fires on "suitable" days--days when lightning activity had been forecasted and which since had been randomly treated. The randomization schemes insured that, whatever the total number of suitable days, about half were impartially selected for treatment. The remainder, impartially left unseeded, served for comparison. In 1958 lightning fires were counted within a prespecified target (3,000 square miles in eastern Plumas and southern Lassen Counties) on 26 suitable days--13 randomly seeded, 13 randomly not seeded. In 1959 these counts were made in a prespecified target (540 square miles around Eagle Lake in Lassen County) on 21 suitable days--11 randomly seeded, 10 randomly not seeded.

The design used in 1958 and 1959 eliminated the need to establish areal target-control relations, as in 1957, since the target served as its own control on unseeded days.

It would have been shortsighted to restrict the multiple regression analysis only to lightning fire counts. In fact, evaluation of an effect such as the influence of seeding on summer precipitation (largely rain, some hail) was a necessity, since most foresters would not want to reduce lightning fires at the expense of reducing rainfall at the same time. Hence, in 1958 and 1959, precipitation data were especially collected for the same kind of regression analysis as the lightning fire data. Additionally, special attention was given to lightning discharges in 1958 and 1959 and to ice nuclei in 1957, 1958,and 1959.

The number of lightning discharges was counted with Meteorology Research, Incorporated, lightning counters. Unfortunately instrument deficiencies make discussion of these data unprofitable.

Ice crystals were counted with an airborne portable cold-box, also manufactured by Meteorology Research, Incorporated. Only the 1959 counts were suitable for regression analysis.

Some investigation was made of bordering lightning fires, bordering rainfall, man-caused fires, burning indexes, and lifting condensation temperatures. One analysis indicated a rainfall increase in 1958 in an area north of the target. However, it and all similar analyses must be regarded with caution since they are undesigned.

Results

The results in order of importance fall into three groups--those for number of lightning fires (table 1), amount of precipitation (table 2), and number of ice nuclei (table 3). The quantities in these tables are averages and significance probabilities, the averages observed directly or calculated from the linear regression equations. Clearly, year-to-year differences in the averages occur mostly because of year-to-year differences in the "experimental units," as emphasized by the underlining in the first column of each table.

Table 1.--Average numbers of lightning fires rounded to nearest 1/2, and corresponding significance probabilities, 1957, 1958, and 1959

Year and experimental unit	Observed seeded incidence	Calculated incidence if had not seeded	The approximate chances (two-sided) that difference is accidental
1957:			
number during whole year in Lassen plus Plumas National Forests, about a 6,000 sq. mi. target	60	180	6 out of 100 [1]
1958:			
number per suitable day [2] in east Plumas and south Lassen Counties, about a 3,000 sq. mi. target	6	2	23 out of 100
1959:			
number per suitable day [2] around Eagle Lake in Lassen County, about a 540 sq. mi. target	1-1/2	1/2	38 out of 100

1/ From most favorable of six analyses; mean of all six was 15 chances out of 100.

2/ Suitable for randomized treatment because lightning storms forecast

Table 1 illustrates nicely the possibilities of bias when, as in 1957, no design is used. The results tabulated for 1957 present only the most favorable case for a beneficial effect of seeding. This case was chosen from a total of six regressions computed from six different combinations of the same basic data. The other five consistently indicated a beneficial effect of seeding, but they also indicated higher probabilities of accidental occurrence. The highest probability was about 25 chances out of 100; the mean of all six probabilities, about 15 chances out of 100. Hence 15 chances out of 100 should be taken as more representative of the likelihood that 1957 results were accidental.

Table 2 shows no 1957 results because, although several relationships were investigated, no good target-control relationship was found. In the other two years, the odds were high that differences in precipitation between seeded and unseeded days were due to chance.

Table 2.--Average inches of precipitation to nearest hundredth, and corresponding significance probabilities, 1958 and 1959

Year and experimental unit	Observed seeded amount	Calculated amount if had not seeded	The approximate chances (two-sided) that difference is accidental
1958:			
number per suitable day[1], measurements at 10 recording installations in east Plumas and south Lassen Counties, roughly sampling the 1958 lightning fire target	.68	.36	47 out of 100
1959:			
number per suitable day[1], measurements at 10 recording installations around Eagle Lake, roughly sampling the 1959 lightning fire target	.17	.26	75 out of 100

1/ Suitable for randomized treatment because lightning storms forecast.

Table 3 also shows no 1957 results because no good target-control relationship could be found and also because cold-box observation temperatures varied excessively. No 1958 results are shown because nearly all sampling flights were on seeded days, so that it was not possible to establish the mean unseeded count of ice nuclei (background count). In 1959 roughly the first third of the data were not useful, again because of excessive variation in cold-box observation temperatures. These observations

were deleted in computing the averages of table 3, but even when included they made little difference. The odds were low that differences in number of nuclei were due to chance.

Table 3.--Average number of ice particles "active" at -18°C ± 1°C, rounded to nearest 1/2, and corresponding significance probability, 1959

Year and experimental unit	Observed seeded count	Calculated count if had not seeded	The approximate chances (one-sided) that difference is accidental
1959:			
number per suitable flight-day[1], measurements at 24 standard grid-points uniformly spaced over Eagle Lake and environs, roughly sampling number of "active" ice nuclei near cloud base levels within the 1959 lightning fire target	3-1/2	1	3 out of 1,000

1/ Suitable for randomized treatment because lightning storms forecast

Conclusions

1. For the lightning fire averages, no probability of accidental occurrence was as small as 5 chances out of 100. Hence seeding from the ground in 1957, 1958, and 1959 did not significantly increase or decrease the incidence of lightning fires.

2. For the average precipitation amounts, no probability of accidental occurrence was as small as 5 chances out of 100. Hence, seeding from the ground in 1958 and 1959 did not significantly increase or decrease the precipitation.

3. For the average ice nuclei counts, the probability of accidental increase was much less than 5 chances out of 100. Hence, seeding from the ground in 1959 significantly increased the average number of ice nuclei "active" at about -18°C., near cloud base levels, within and around the 1959 lightning fire target.

Discussion

The California Division of Forestry has stated in operating instructions issued to field personnel in 1958 that "What the California project is now trying to accomplish is to establish the extent to which the incidence of lightning caused fires can be reduced by cloud seeding . . ."(underlining added). Therefore we have emphasized the analysis of lightning fire incidence. In economic terms, however, the Division probably is more interested in reducing the damage from lightning fires rather than merely their incidence. Foresters are well aware that the two are not necessarily equivalent. A "dry" lightning storm may set only a few fires, but the damage may be great.

Because of the spotty but intense character of summertime showers, the rain gage network used was a poor method for detecting an increase in precipitation due to seeding. Thus, in 1959, even though the network had been specially augmented by the Department of Water Resources, one gage in 30 minutes caught 43 percent of all the rainfall recorded by all 10 gages on all 21 suitable days. Such occurrences introduce excessive variability into the record and obscure all but the most extreme effects of seeding.

When and where cold-box temperatures were controlled, the ice nuclei counts are some of the most unbiased evidence to date that silver iodide generators operated from the ground can increase numbers of ice-forming nuclei 4,000 to 6,000 feet off the surface. At some individual grid points the local average increases ranged from 15 to 19 times the local average background. Nevertheless, the area-wide average increase was only 3-1/2 times the area-wide average background, even though generators were massed in a small target, half were operated from well-exposed locations such as lookouts, and weather conditions generally favored convective transport of the nuclei aloft. Concentrations of at least 100 times the local background appear theoretically more desirable.

It is recognized that the statistically inconclusive results for lightning fires and precipitation may be due simply to treating too small a sample. In this respect, because sample sizes were not predetermined, the designs were lacking.

Recommendations

1. End any plans for a routine operational program for seeding from the ground.

2. Design and evaluate a randomized experiment with airborne silver iodide generators. Preliminaries might include:

   a. Location of breeding areas and favored storm tracks, if such exist.

   b. Development of stronger regression equations to better predict what would have happened in the absence of seeding. These equations will increase the chances of

detecting a significant effect, if it exists. The alternative would be to increase the sample size, which might take years.

c. Development of better measures of the effectiveness of seeding and better measuring techniques.

3. Continue to monitor appropriate research activities, such as Project Skyfire, for new developments in weather modification.